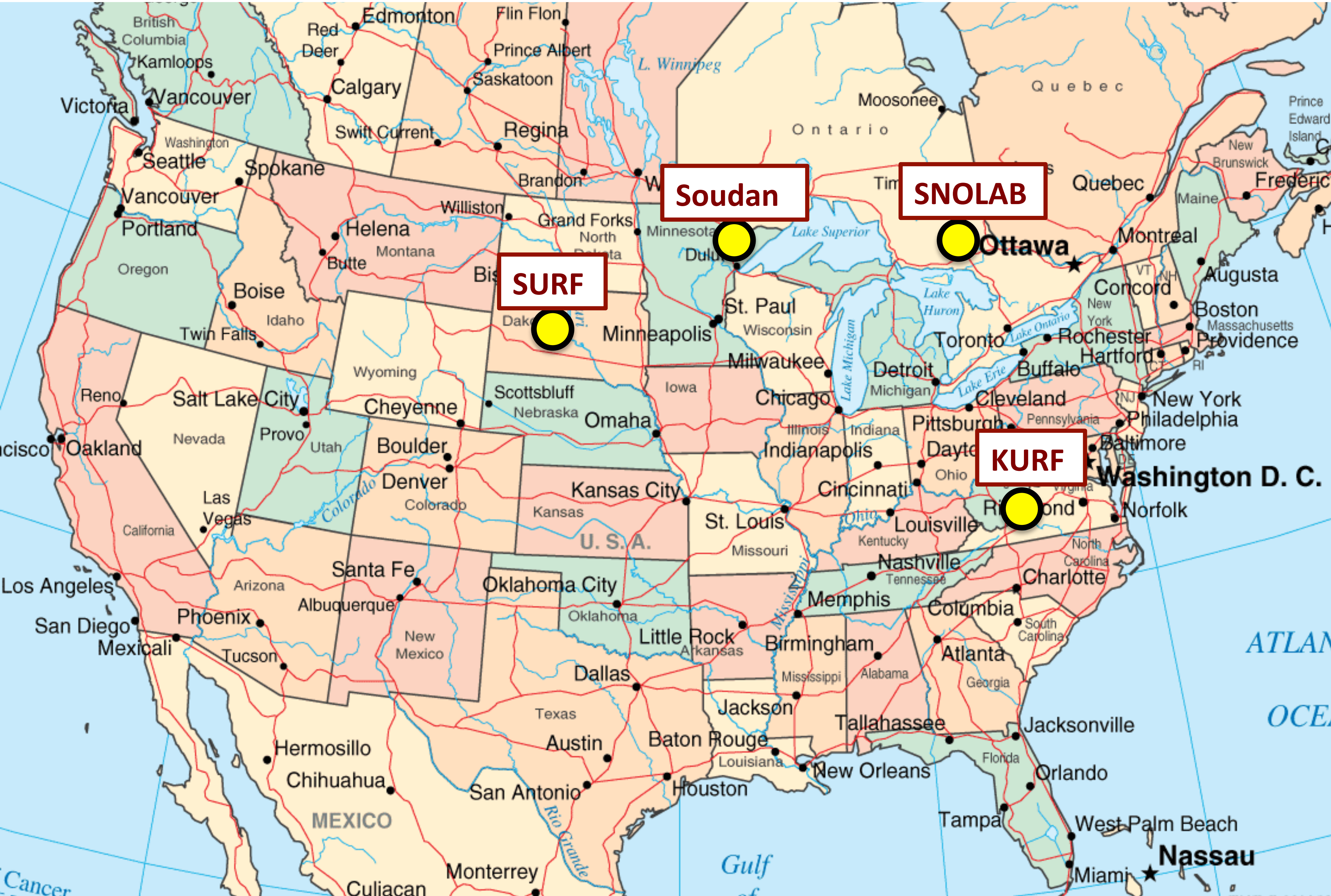
Low Background User Facilities in the US

Toward a coherent US program in Assay and Related Technologies

Priscilla Cushman
University of Minnesota

DURA Meeting
SLAC March 5, 2013

Underground Sites for Low Background Counting



Which aspects of "Low Background" require an Underground Facility?

New highly sensitive screeners

GeMPI style gamma spectroscopy (ultralow background shielding and crystals)

R&D on new types of screeners (e.g. beta cage, XIA alpha counter, ..)

Stockpiling of materials to avoid cosmogenic activation

Prototyping new experiments: How do you stage a new experiment?

1. Prove the technique works (in a convenient lab)
2. Make it "low background"
   a. decide on materials (requires use of screening detectors)
   b. run it underground and get a physics results as well as proof of principle
3. Discover unexpected background sources (run underground)
4. Scale up and run for a long time (deeper underground)

Develop new active veto strategies for α-n, SF neutrons

Benchmarking Simulations to improve underlying physics in Geant4 and FLUKA

Summary

- SNOLAB PGT HPGe low background counting system has run continuously for the past since 2005 and has counted 296 samples so far.

  Counting queue in unusually long at 19 samples, this sometimes limits when samples can be counted in a timely manner.

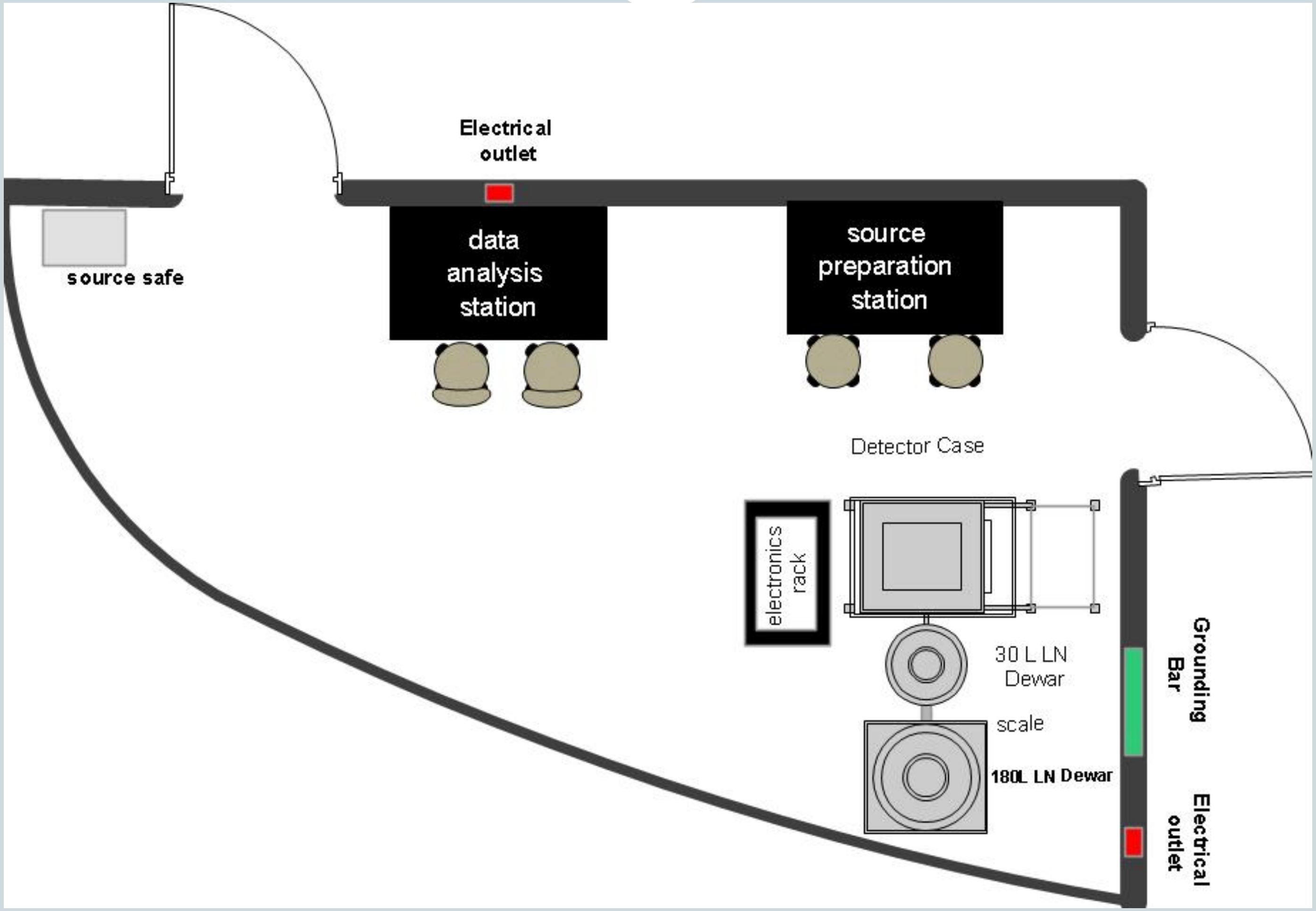
  The counter(s) is available for all SNOLAB experiments and can be made available to non-SNOLAB experiments upon request.

- Two new Canberra Ge detectors were delivered to SNOLAB, but are now being refurbished since they are not ultra-low background as expected.

  The new counters should allow much higher sensitivity, effort underway to ensure all materials are low background. The well detector will be used for very specialized small samples such as vapourized acrylic.

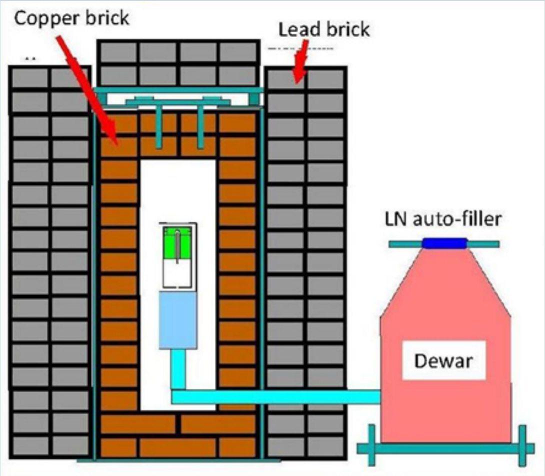
- Specialized counting can be done using the ESC or Alpha-Beta Counters and materials can be emanated for Radon.
- New low background counting lab is being constructed at SNOLAB, final preparations are now underway.

Planned LBC Facility in the East Counting Room of the Lower Davis at SURF



LBC Phased Deployment Plan

schedule is tentative pending approval from SURF. Details are available in the document entitled "Schedule for the delivery and setup of the LBC" available on the SURF docushare at:
https://docs.sanfordlab.org/docushare/dsweb/View/Collection-17033



- Phase 1 – Delivery and installation
  March 4 2013- Mar 7 2013
- Phase 2 – Pre Pb Characterization Operations
  March 7 – April 1
  - Configuration 1 – bare Ge (1 day)
  - Configuration 2 – Cu shield (~3 weeks)
- Phase 3 – Pb cleaning operations
  April 8 – 12
- Phase 4 – Post Pb Characterization Operations i.e., Configuration 3
  April 1 – May 1
- Phase 5 – Commissioning and General SURF availability of LBC facilities
  May 2 – online for LUX/LZ screening (expect 0.1 ppb)

SURF Proposals for the Future.

Research Innovation Center (RIC) through South Dakota and NSF EPSCoR:

A 10 ppt screening detector in 2015

A GeMPI detector with 1 ppt screening detector in 2017

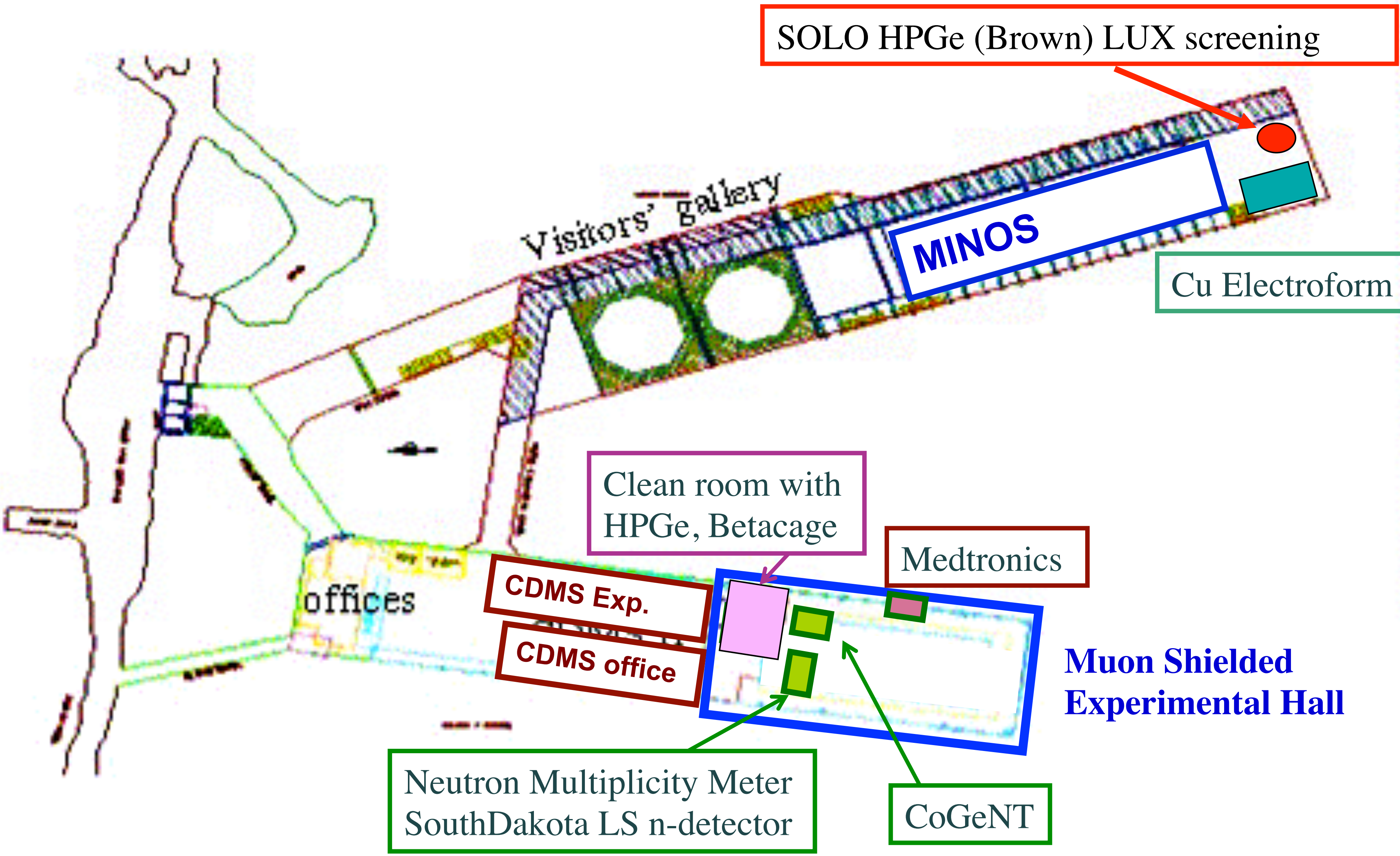
Managed by USD, BHSU, LBNL, and SURF
Serving Majorana Demonstrator and LZ

NSF Major Research Instrumentation

A neutron screening detector installed in the LUX tank in 2016

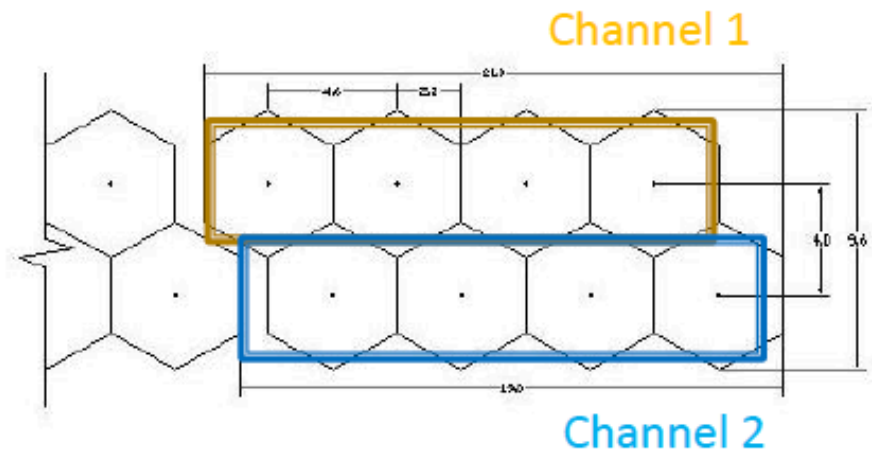
Managed by USD, UC SB, Brown, BNL, LUX, and SURF
Serving Majorana Demonstrator and LZ

The Soudan Underground Lab: Low Background Capabilities

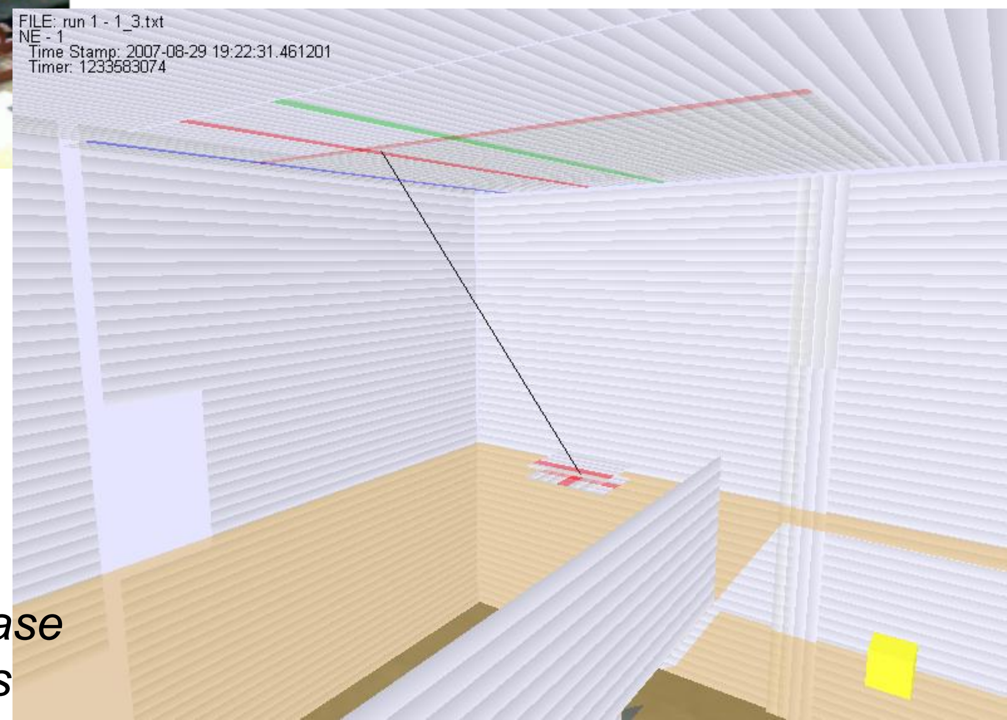


Muon Shielded Experimental Hall (35' x 40' x 100')

Proportional Tube Muon Veto from old Soudan2 Proton decay experiment

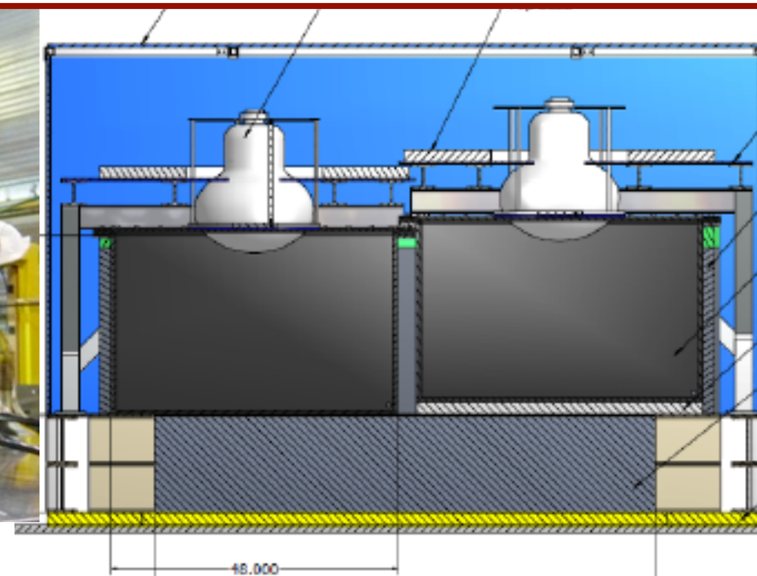


- Tubes refurbished
- Gas System rebuilt with new readout/control system
- New DAQ
  - *Reconfigurable trigger with CPLDs*
  - *LabView Readout and MySQL database*
  - *GPS-based time stamps on all events*



Combine muon tracks with Neutron Detection to get a handle on neutron backgrounds
Benchmark cosmogenic neutron Monte Carlos (Geant4, FLUKA).

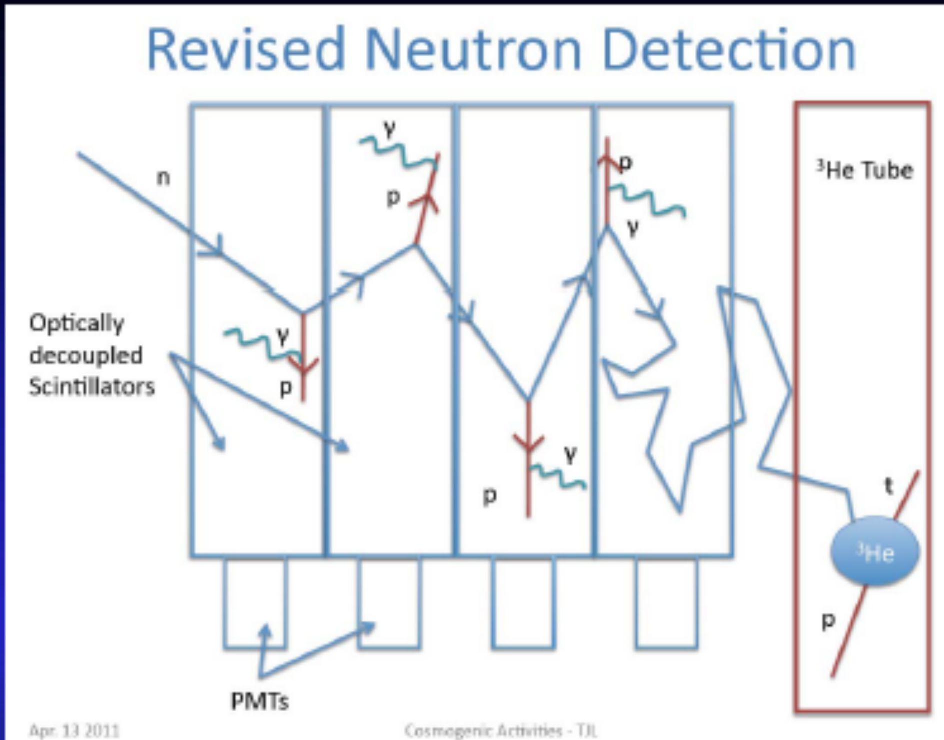
The Neutron Multiplicity Meter
UCSB, Case, Syracuse, UCDavis

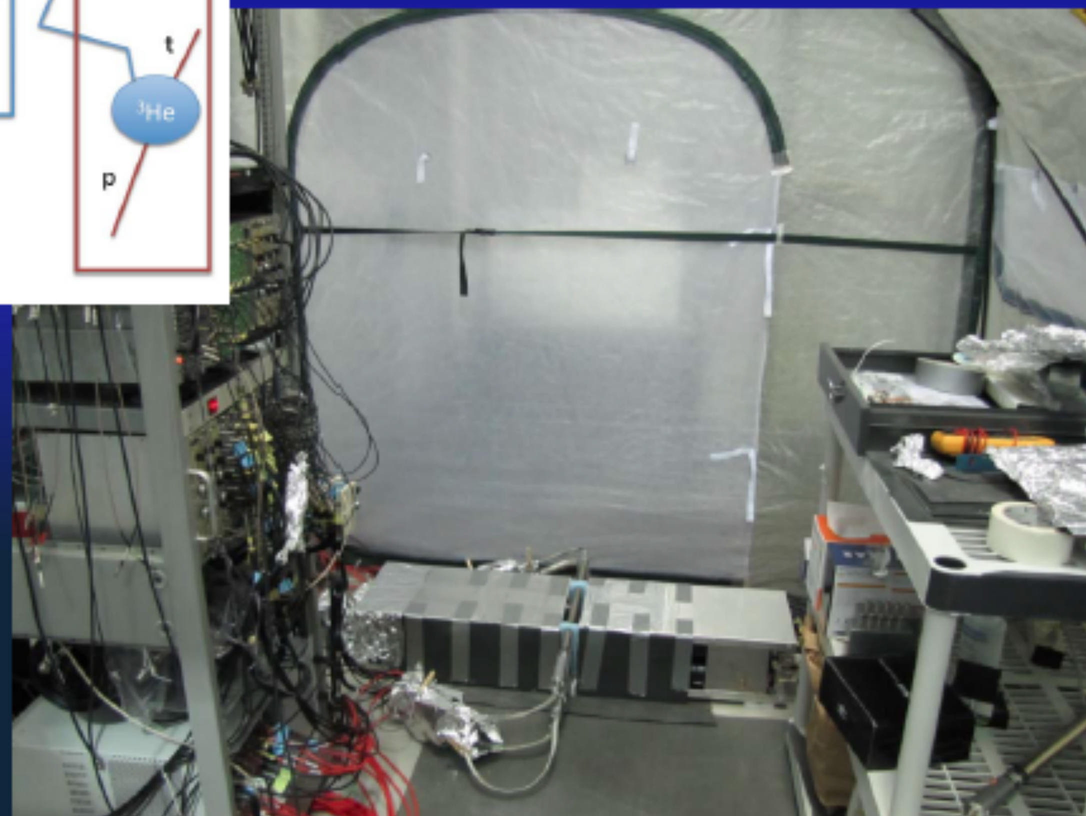


University of South Dakota Liquid Scintillator Neutron detector

Kimballton

UMD-NIST
Fast Neutron
Spectrometer

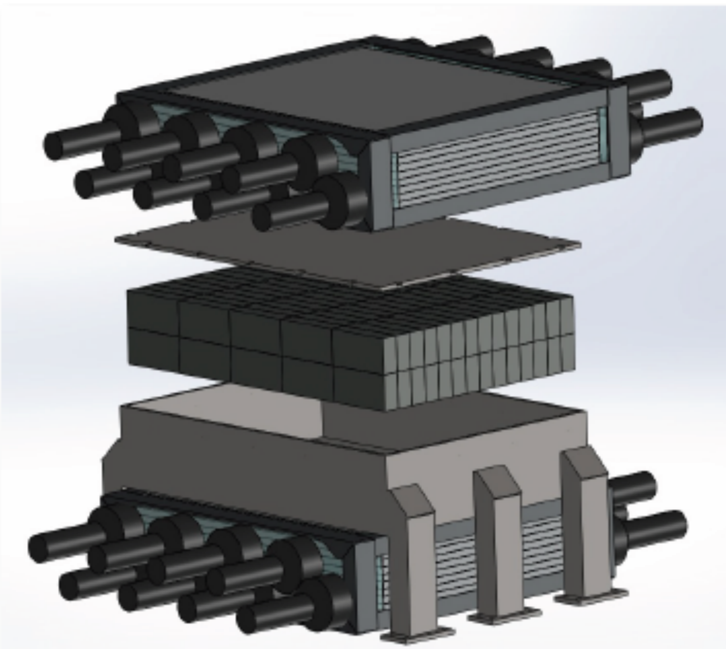


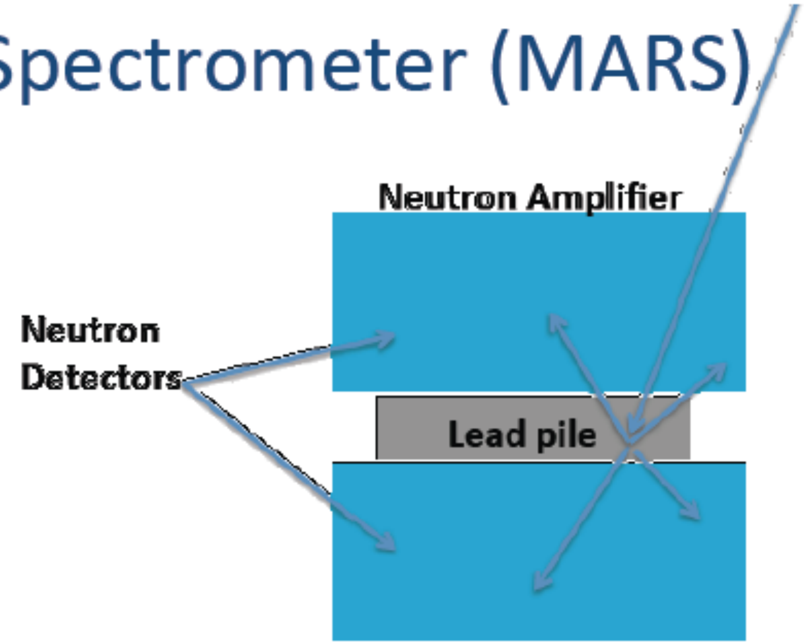


Watchman Project: Water Cherenkov Monitoring of Anti-neutrinos

LLNL, Sandia, UC Davis, UC Berkeley, UC Irvine, Hawaii

Phase I: Fast Neutron detector Multiplier and Recoil Spectrometer (MARS)

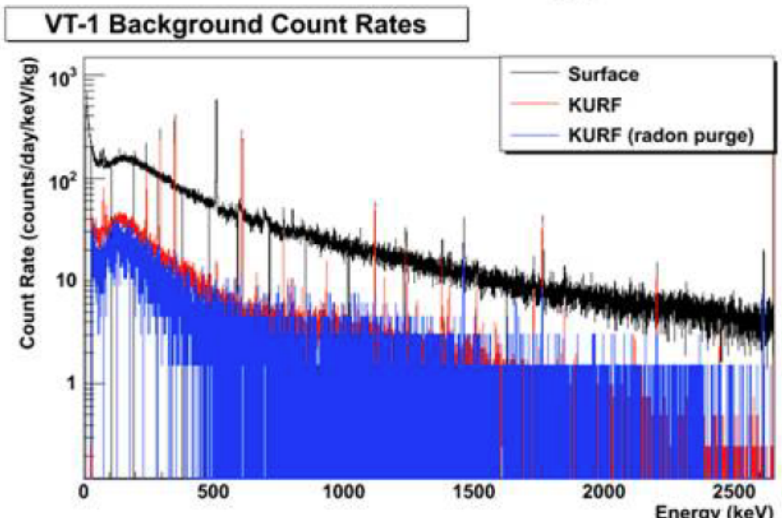


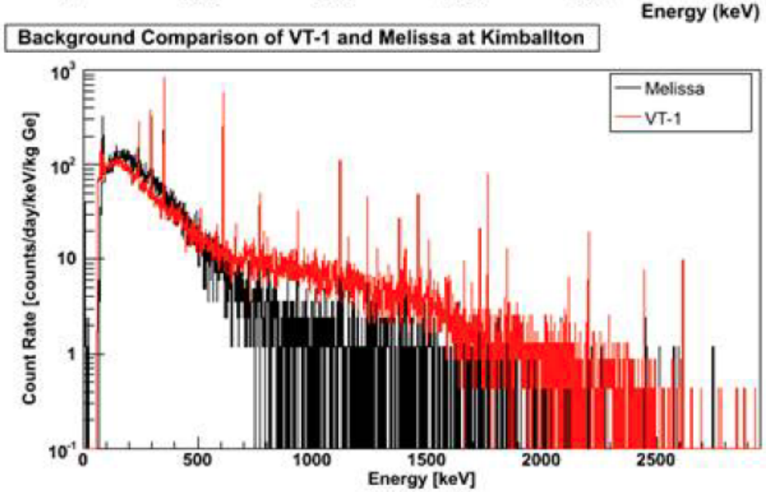


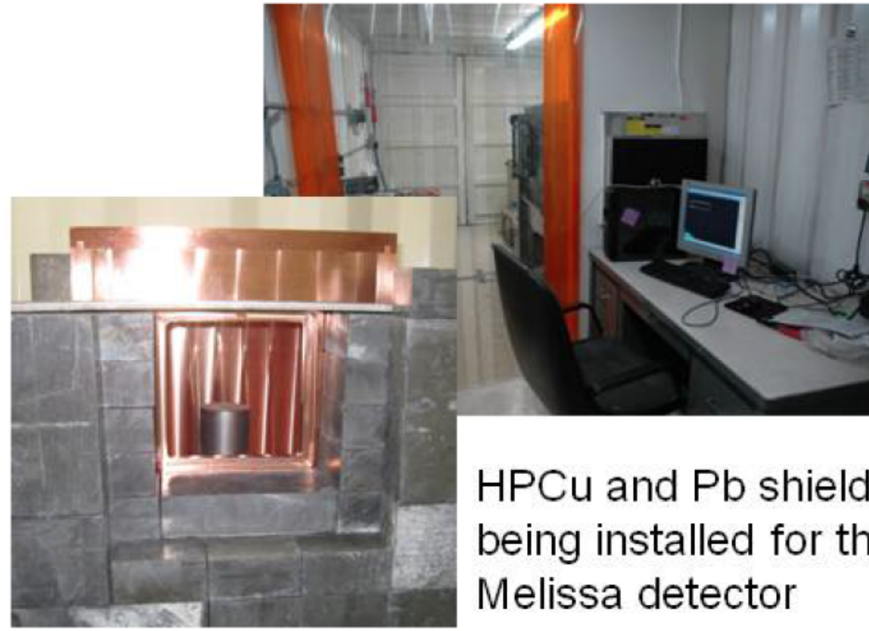
Set a flux at different depth and do relative measurements

- Plastic scintillator/Gd doped paint detectors sandwich ~4 tons of lead.
- Direct interaction with scintillator for E < ~100 MeV.
- Neutron multiplication off of the lead for E > ~50 MeV.
- Expect 3000-5000 events per month at 100 m.w.e.

"VT-1" and "Melissa" Low-Background Detectors







HPCu and Pb shield being installed for the Melissa detector

Species	E [keV]	Melissa	VT-1	Surface
^{214}Pb	352	840	60	100
^{214}Bi	609	470	30	100
^{40}K	1460	30	30	30
^{208}Tl	2614	4	10	70
Integral (cpd/kg)	**40-2700**	**40k**	**7.3k**	**380k**

Underground Screening Facilities have complementary strengths

SNOLAB 6010 m.w.e.

Deepest site and most developed infrastructure.
Current cooperation at the level of AARM (e.g. Universal Database)
Shared technology transfer worldwide (LRT, AARM)
Future resource sharing can be developed via MOU.
Funding sources can remain separate.

SURF 4300 m.w.e.

Shares location with users: LUX and Majorana Demonstrator
On-site staff
Cryogens, LUX shield, Purification plant, Cu electroforming

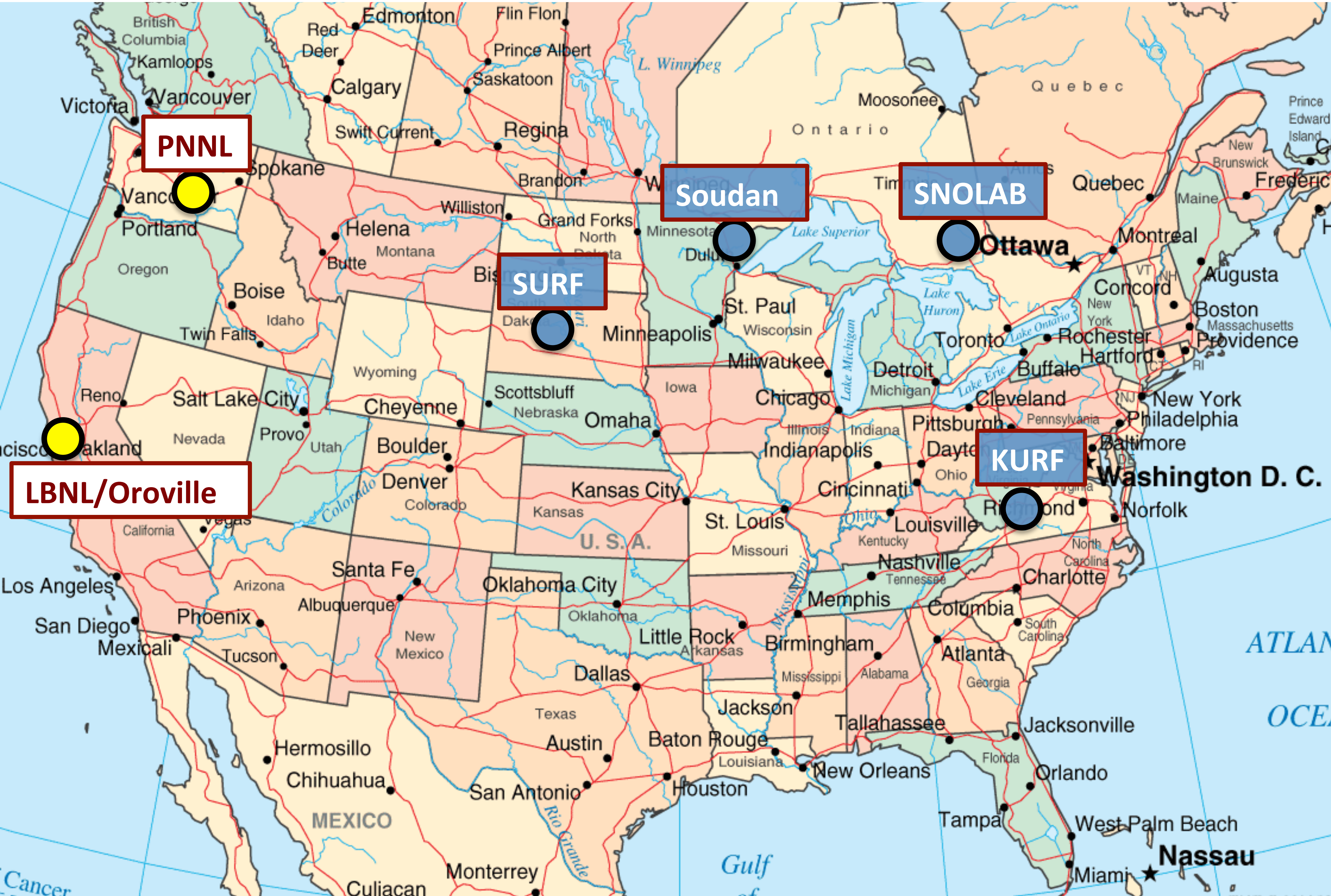
Soudan Underground Lab 2100 m.w.e.

Shares location with user: SuperCDMS, remote user: LUX
On-site staff
Muon-shielded room and cosmogenic neutron studies, neutrino beam

KURF 1450 m.w.e.

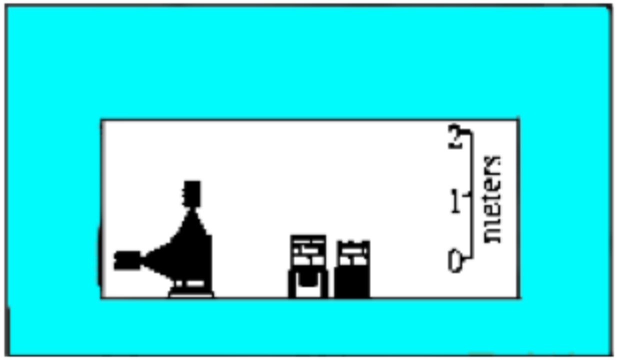
Operate 2 HPGe for Majorana Demonstrator
Trained users/students close by.
Drive-in facility, low radon, easy access to multiple depths, fast neutron studies

Shallow Underground Sites for Low Background Counting



LBNL Low Background Facility

Surface Site at LBNL
cave constructed of low-activity concrete
active muon veto.



Oroville, Dam. ~600 m.w.e. overburden

Counting Sensitivities (for ~1kg samples)	Berkeley Site @ ~1 week	Oroville Site @ ~2 weeks
U series	0.5 ppb	50 ppt
Th series	2.0 ppb	200 ppt
K	1.0 ppm	100 ppb
Co-60	0.04 pCi/kg	0.004 pCi/kg
	BKG dominated by cosmic ray muons	BKG limited by material contamination (shield/detector)

LBNL Low Background Facility

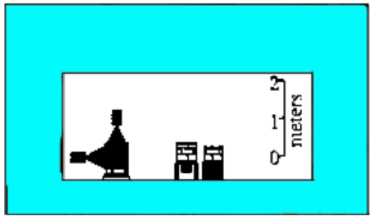
A.R. Smith, Y.D. Chan, K.J. Thomas, E.B. Norman, D.L. Hurley

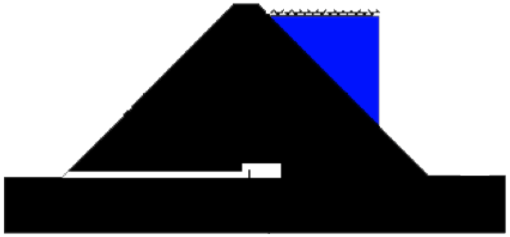
Expertise in Low Background Gamma Spectroscopy

- Primary HPGe Spectrometers: (1) 115% n-type, (2) 85% p-type, (+others)
- Passive Assay of U, Th, K (and ^{60}Co, ^{137}Cs, cosmogenics, etc.)
- Active Assay via Neutron Activation Analysis
- Low activity NaI and BF3 counting also available, Rn, ICPMS via ESD
- 50+ years of LBC experience.

Activities/Clientele

- SNO, KamLAND, CUORE, DoubleCHOOZ, Daya Bay, Majorana, Katrin, Sanford Lab, LUX, LZ
- LBNL EHS waste assay
- Environmental Monitoring (Fukushima fallout)
- Active Participation in Nuclear Science and Security Consortium (NSSC)





LBNL Low Background Facility

“Wish List” of Future Plans

- Local Site: Addition of 2 new, large detectors with shared anticoincidence shielding and Pb shield, in a re-configurable orientation to allow coincidence counting.
- Oroville Site: Two new detectors, including a large n-type, for use in existing large Pb shield.

Budgetary Comments

- Low cost of operations: Primary costs are Humans and Liquid Nitrogen. Fairly Lean.
- Additional Grant Funded has been sought for additional detector(s) in past, and still currently planned.
- Funding provided by DOE/NSD and experiments/client recharge accounts with LBNL.
- NSSC participation including some tech. upgrades and personnel training (K. J. Thomas)

Community Ties

- Current activities to convert 50 years of counting results to make accessible online
- Current collaborative LBC associated with USD/Sanford Lab

Underground Lab provides low backgrounds for measurements and materials synthesis

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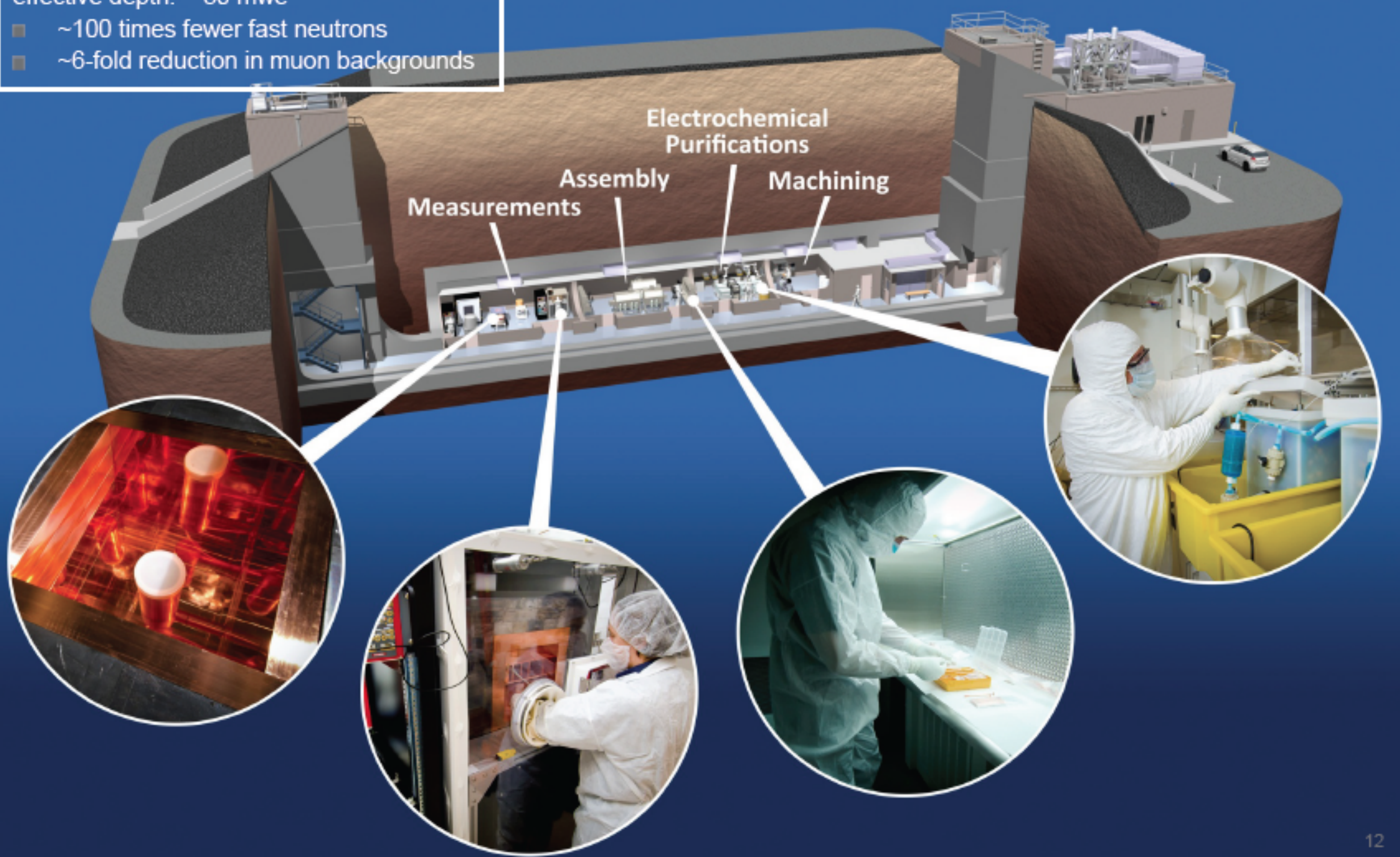
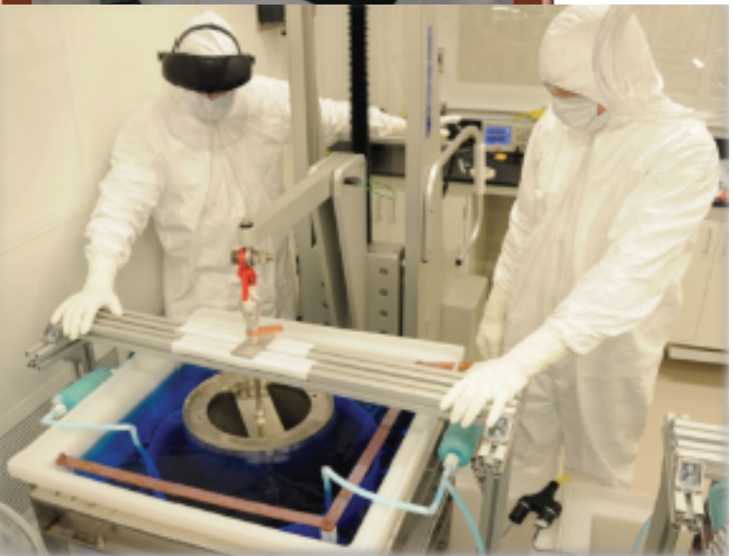
effective depth: ~30 mwe
- ~100 times fewer fast neutrons
- ~6-fold reduction in muon backgrounds



Scientific Challenge

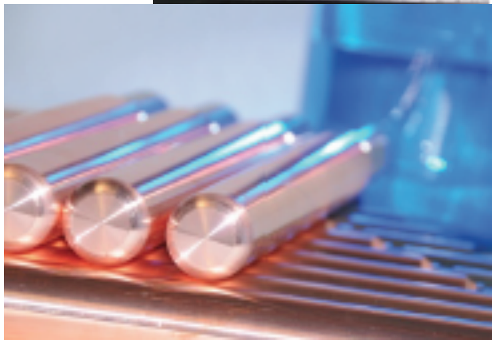
Evaluate impact of geologic argon produced by FNAL Dark Matter group as an ultra-clean material enabling more sensitive measurements and geochronology

- Ultra-Low-Background Proportional Counter (ULBPC)
  - An effort to produce a low-background, physically robust gas proportional counter for applications like:
    - Radon emanation
    - Groundwater tritium
    - ^{37}Ar measurements



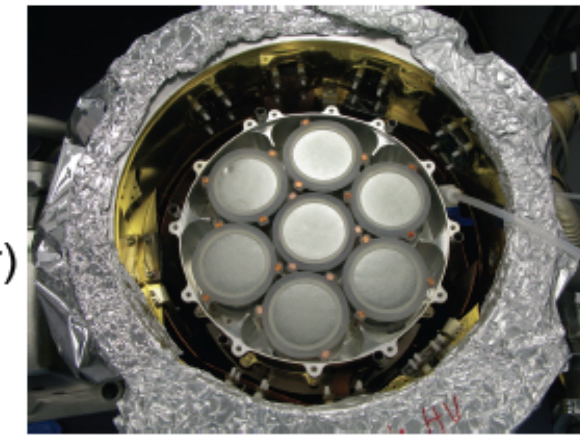
Electroforming ultra-high purity copper for cryostats and other assembly materials.

Lead institution installing SURF electroforming baths for Majorana Demonstrator



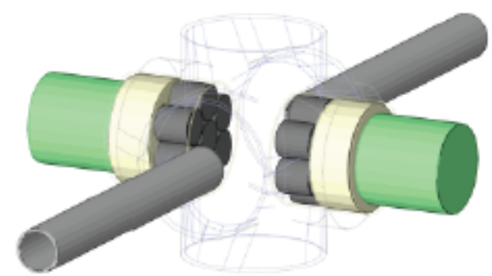
HPGe detector arrays

- PNNL has extensive experience with ultra-low-background single-crystal HPGe to larger HPGe arrays over the last 10 years



- Two Example HPGe Array Detector Systems
  - MARS (Multisensor Airborne Radiation Sensor)
  - RN LABS (Radionuclide Laboratory System)
  - UHRGe (Ultra-High Rate Ge)
    - Highly synergistic with Mu2e

- Technology from this work has made its way into basic science, e.g., neutrino and dark matter experiments



- FRIB
  - Gas Jet HPGe Detector Array
  - Decay Station HPGe Detector Array
  - Workshop on HPGe Detector Arrays in May

Counting isn't the whole story.

Surface analysis:

Probe elemental composition, sub-micron position and depth profiles.. using ion or electron beams, X-rays, etc: RBS, XRF, FReS, NRA, Auger, PIXE …

Available in many institutions, but in-house capability provides fast turn-around and expertise

Mass Spectroscopy: *ICPMS, GDMS, TIMS, SIMS, AMS*

Extract and accelerate charged ions from a sample and measure the trajectory corresponding to the correct charge-to-mass ratio for the element in question.

Quoted sensitivity depends on magnetic spectrometer and sample dispersion technique

Real sensitivity depends on details of the sample prep and chemistry

Range of materials depends on R&D in digestion and dissolution techniques.

Neutron Activation Analysis

Induce neutron capture on sample and detect (via HPGe) γ-rays from de-excitation

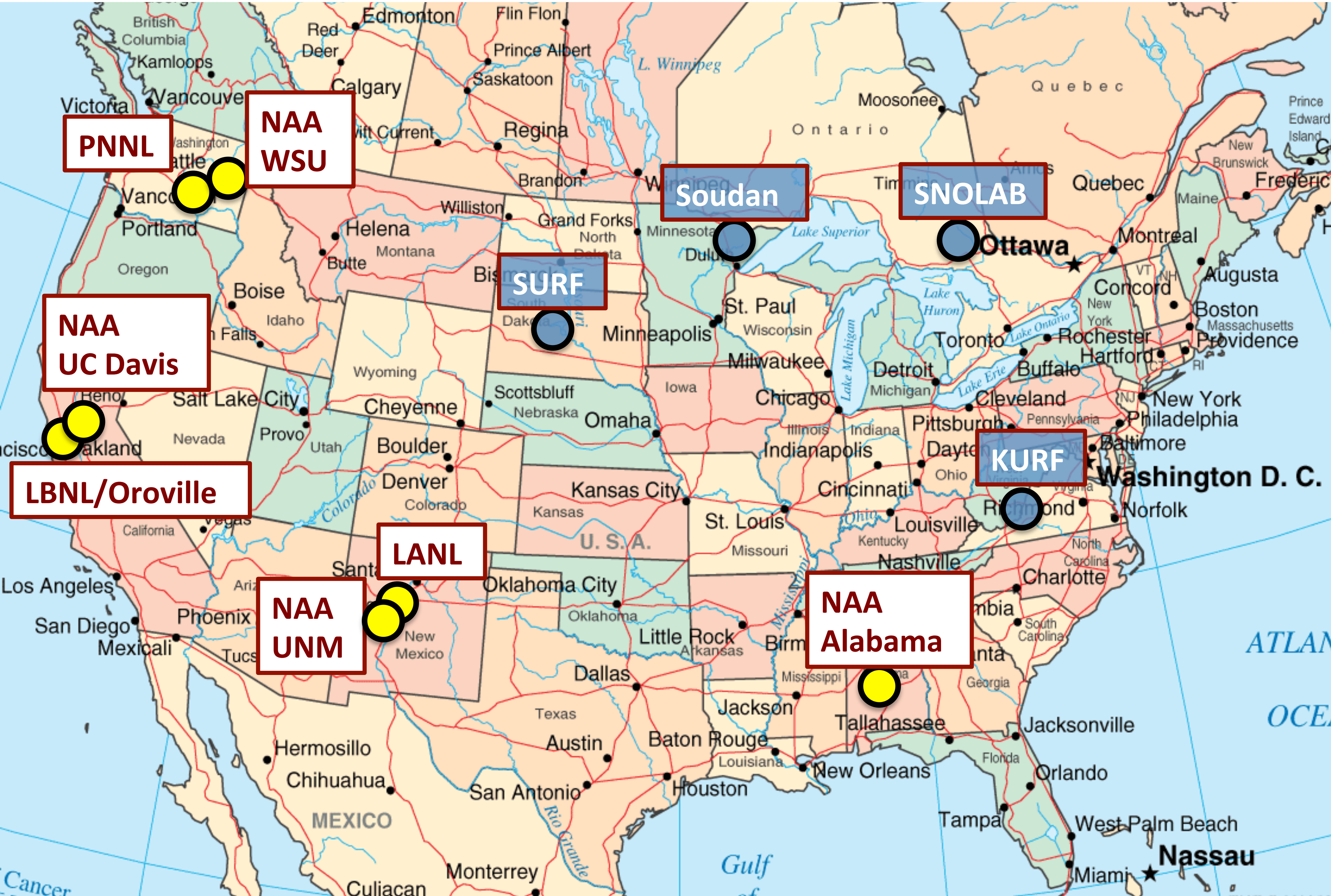
Either prompt (usually in-situ) or delayed (ship to site).

Requires reactor > 10^{13} n cm^{-2} s^{-1} (or DT plasma generator)

Technique limited by the nuclear properties of trace element (~60% of elements activate)
and substrate (activation of substrate masks lines)

> ICPMS and NAA have proven their worth for HEP
> Experienced Personnel (and maintaining that expertise beyond projects) is VITAL.

Other sites for HEP/NP Low Background Characterization



NAA at the University of Alabama

Mashup of Andreas Piepke's slides

NAA since 2001: activated and analyzed more than 200 samples

Project Driven: KamLAND and EXO experiments. No commercial or other users
Recently joined LZ and now the facility will be doing nEXO and LZ samples

MIT research reactor (MITR), utilizing its 2PH1 sample insertion facility:
Irradiations from 2- 12 hours (disposable polyethelene or quartz irradiation containers)

- Thermal n-flux: $5.5 \cdot 10^{13}$ n/cm$^2 \cdot$s
- Epi-thermal n-flux: $9.5 \cdot 10^{11}$ n/cm$^2 \cdot$s
- Fast fission n-flux: $2.0 \cdot 10^{12}$ n/cm$^2 \cdot$s
  - have also worked with HFIR at Oak Ridge National Lab.

All pre- and post irradiation handling is performed at UA.

- Class 500 clean room (with chemical fume hood) for clean pre-activation handling.
- Sample and container preparation using ultra-clean chemicals.
- Sample counting ~ month, to optimize sensitivity (Th-activation product ^{233}Pa)
- Double differential energy and time analysis.

Analysis of compatible materials (no post-radiation radiochemistry)
Regularly achieve sensitivities of K- 5 ppb Th- 1 ppt U- 1 ppt
Post-irradiation ion-exchange separation on LS samples improved Th/U to $\sim 10^{-14}$ g/g.

At UA we have handling permits for open radioactivity
All post-irradiation sample preparation can be in-house.

We operate three Ge detectors, two of them are low background capable and are thus dual purpose.

Chris Grant, Jeremy Mock,
Bob Svoboda, Mani Tripathi

TRIGA Mark II Reactor: 2 MW max, 1.5 MW typ, ~1000 MW per 20 ms pulsed

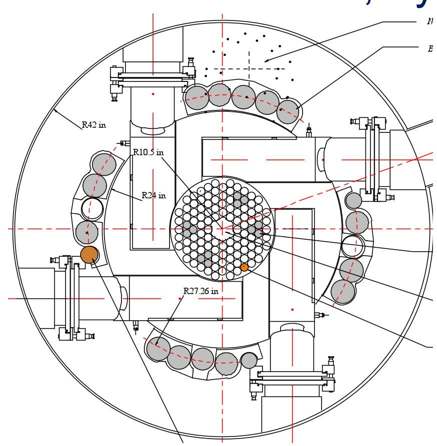
Reactor managed by UC Davis. NAA work funded by DOE/NNSA training grant (NSSC)

Easy access for experimenters – open for collaborative work.

Four high purity Ge detectors (Canberra) - 8, 25, 50, 99% efficient

D2O module being developed for controlling Fast/Thermal neutron flux

Screening work for LUX/LZ. Generic work with PNNL, Syracuse, UC Berkeley.



Neutron Activation Analysis continued…

Other HEP-related NAA Axes:

Washington State University NRC (1.3 MW TRIGA reactor) + PNNL
University of New Mexico (AGN-201) + Los Alamos

Even more examples

University of Wisconsin research reactor: **DOE reactor sharing program** is a way to defray costs and create a user community.

University of Missouri research reactor: Analysis (and samples) go through the archaeometry lab. **NSF-Subsidy Program for Geoarchaeological Analysis**
The Archaeometry Laboratory's NSF subsidy increases availability of analytical methods to archaeologists and encourages increased collaboration between archaeologists and analytical chemists: subsidize select research projects.

North Carolina State NRP uses the 1-MW PULSTAR Nuclear Reactor facility, providing irradiation for students and faculty, but also other users for a fee.

Piepke, "NAA could be made available for other samples. However, such "on demand" service activity would be contingent upon receipt of funding for a postdoc or (better) a dedicated technician. Continuity in sample preparation and handling techniques is, in our experience, key for achieving good and reproducible results."

A complementary suite of background techniques ICPMS, radon emanation, etc. are required to cover all radiopurity and assay needs

ICPMS and other low background techniques require

- Extreme care in sample handling (proper clean rooms and infrastructure)
- Expert techniques in radiochemistry and new R&D
- Continuity of personnel and expertise

Projects build concentrations of talent and equipment, but projects end.

Sustainability can be achieved via

1. National Lab Infrastructure and an Operating Budget
2. Funding from other sources, such as National Security

PNNL has been very successful at leveraging these resources

Following Slides provide some PNNL examples.

But how can we provide such support to all the players in this field? Proposal-driven infrastructure requests have not been very successful at either DOE or NSF without a programmatic impulse behind it.

Generic Materials Assay (ICP-MS)

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Mass spectrometry are performed in clean room facilities on a variety of materials at detection levels that are world leading and in many cases <μBq/kg

Assays at these sensitivities are difficult due to the ubiquitous backgrounds, it isn't the machine, it is the people, methods, and laboratory environment

A wide variety of materials have been assayed including

- Copper, Lead, etc.
- Polymers such as PTFE, HDPE, etc.
- Electronic components such as FET, resistors, cables, fused silica front end boards, epoxies, etc.
- Novel digestion techniques were developed to assay

Method detection limits of copper by ICP-MS

μBq ^{238}U/kg Cu	μBq ^{232}Th/kg Cu	Year
42	12	2005
33	0.6	2008-2009
30	No additional development	2010
1.3	No additional development	2011

Polymer Assay with ICP-MS

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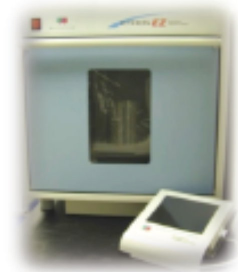
Scientific Challenge

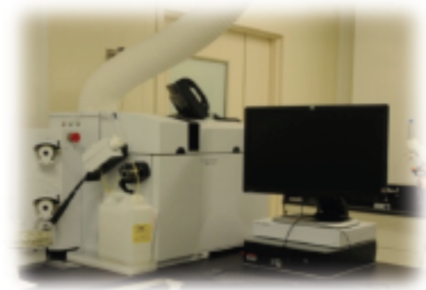
Leverage new approaches to measure trace inorganic compounds in polymer matrices to determine suitability for use "as-is" and, if not, to study contaminant pathways into polymers used within ultra-low background detectors

Scientific Results

- Developed a new assay technique to measure trace inorganic compounds in polymer matrices



- Combined digestion methodologies as needed to create an acid soluble residue from the polymer
- Utilized the Laboratory's high sensitivity mass spectrometry capabilities to perform analysis on the resulting residue for Thorium and Uranium



Why It Matters

- Assay sensitivity at unprecedented detection limits for U and Th (sub µBq/kg) that are relevant to low background detectors in a much shorter time compared to other methods

Developed Cleaning and Passivation Techniques Proven Effective

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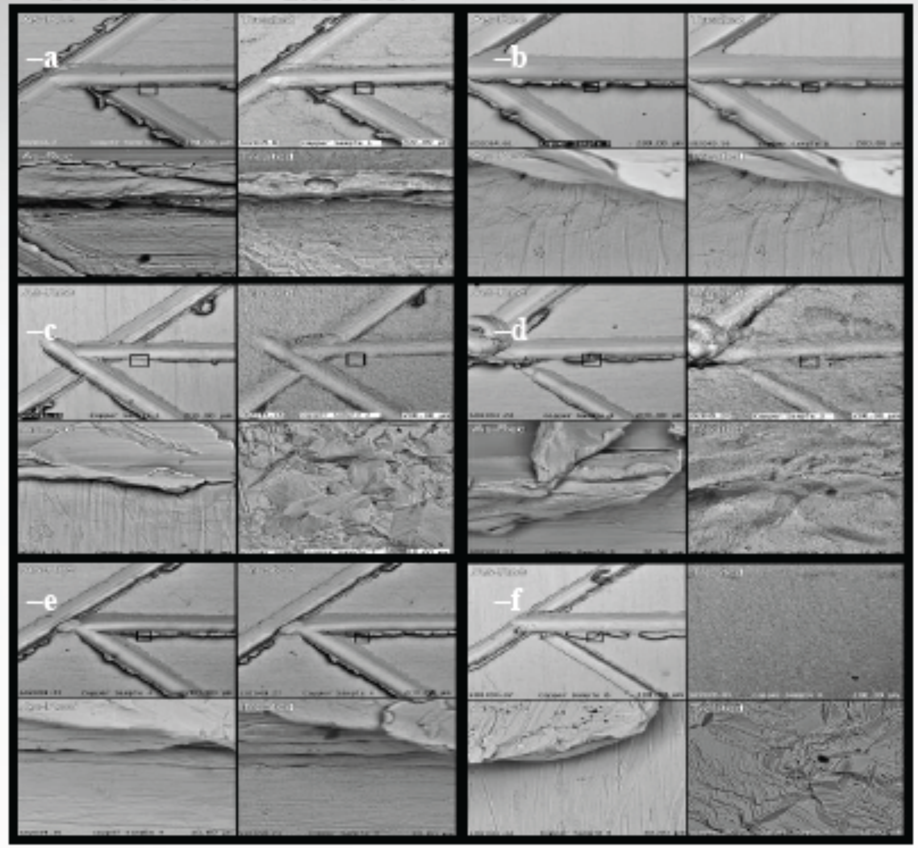
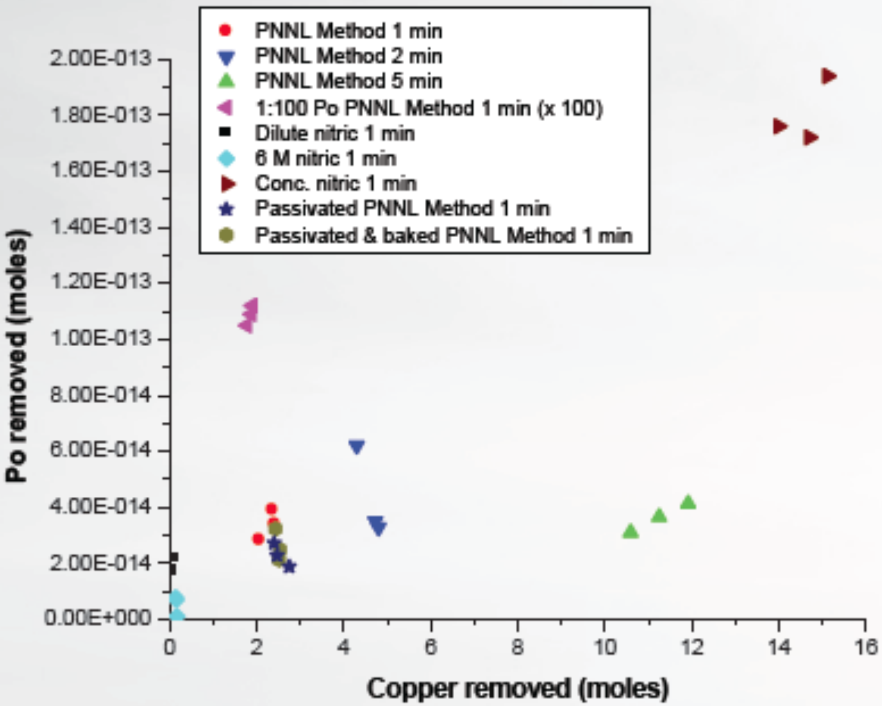
- Evaluated removal of electrochemically difficult species such as polonium from copper surfaces

<u>copper surfaces</u> before etch after etch



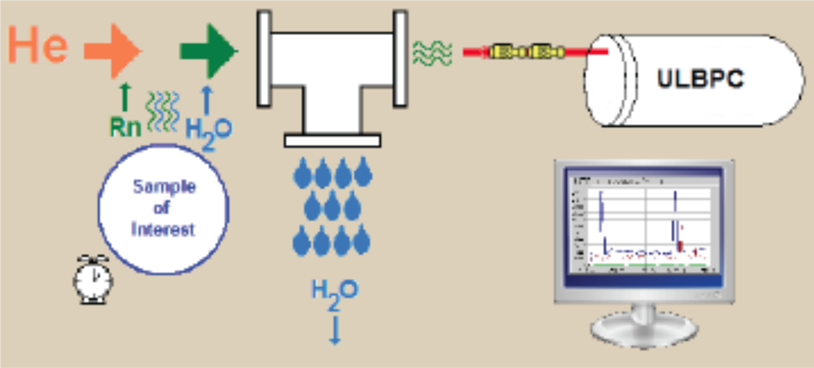


- Conducted numerous studies to determine the optimum surface cleaning and passivation of copper and other surfaces

NIM A 579(1):486-489. doi:doi:10.1016/j.nima.2007.04.101

Radon Emanation as Assay Method

- In assaying low-density materials, e.g. plastics, for radioactive contaminants, standard gamma counting is unfeasible since an inadequate amount can be placed close to the detector. In this situation, radon emanation can be a useful alternative. The technique has the added benefit of being non-destructive in nature.
- State-of-the-art ULB detection capabilities, such as those at the LNGS, Gran Sasso, Italy, possess this capability, yet US laboratories do not.
- PNNL is leveraging prior DOE-funded work to economically produce system
  - sample material is placed in chamber which accumulates radon
  - high-purity helium transfers radon from chamber to cold trap
  - getter pump purifies gas released from trap
  - purified radon along with high-purity counting gas is loaded into a proportional counter



PROPOSAL
HEP Infrastructure Funding for Centers of Excellence in Assay and Related technologies

Assay

HPGe, ICPMS, NAA, atom trap
α,β counting, Rn emanation, etc.

Different Depths
Required for different modalities

Related technologies

Irradiation facilities for NAA,
Radiochemistry for ICPMS

Location & People matter
e.g. Near to reactors,
University partners with expertise

Process

- Capture the existing capability of each Assay Center (shallow and deep)
- Establish centers of specific expertise
- Find a mechanism to integrate these under an umbrella funding and organizational entity

Build on the collaborative work already done by

LRT (Low Radiation Techniques – Biennial International Workshop)
AARM (Assay and Acquisition of Radiopure Materials – DUSEL S4 funding)
Integrative Tools for Underground Science – NSF May 2012 Solicitation

Planning for Common Assay Infrastructure should be part of the Snowmass Process.

Some points from the discussion at the AARM Meeting yesterday

National Labs can provide work for others in a natural way

University physicists are driven by the science, but willing to share if
- their own science is better enabled
  - additional resources for equipment, personnel
  - students can work on many projects

R&D may be part of the mix, but it is trickier
- Publishing rights, competition with other experiments

Independence of scientific direction needs to be maintained by the members
- No “Consortium Dictator” ➔
  - Board of directors needs to contain members from each center

Consortium management by a lab may be prohibitively expensive,
- But how do we set up a structure at a University?

Continue during the CF1 parallel meeting 9 -10:30 Friday

Initial Suite of Assay Centers of Excellence

PNNL (perhaps also the lead institution)

ICP-MS and electro-refinement and actinide chemistry

Gamma Counting

LBNL LBCF, SURF/CUBED, Soudan LBCF, KURF LBCF, PNNL UL

Neutron Activation Analysis

Alabama, UC Davis, Washington State University, University of New Mexico

Add surface alpha, RN emanation, beta counting as we identify a need.

Then add another center or add to capabilities at one of the existing centers.

Fund as DOE-SC User Facilities with budgets to cover measurements and analyses as well as facility maintenance and upgrade. R&D costs as needed (via new proposal from the Consortium) to establish capabilities needed for next-gen experiments.

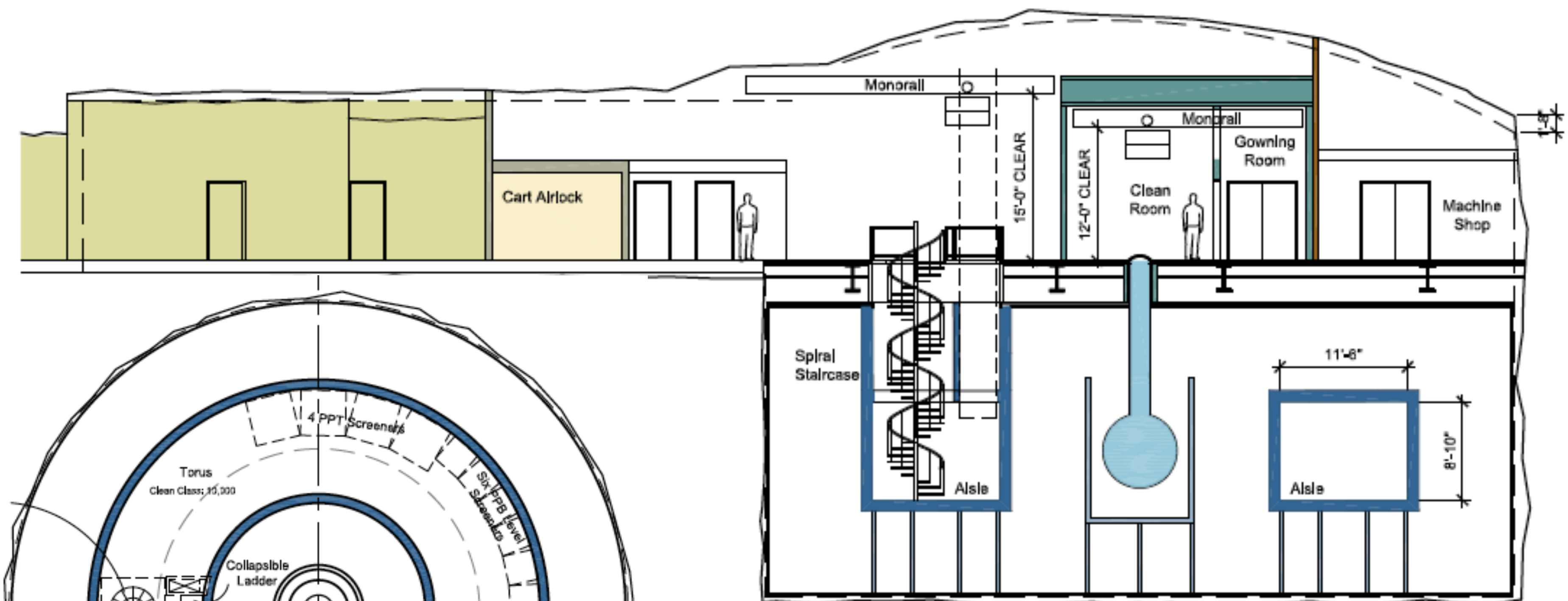
Think of it as transitioning existing facilities into User Facilities to retain capabilities

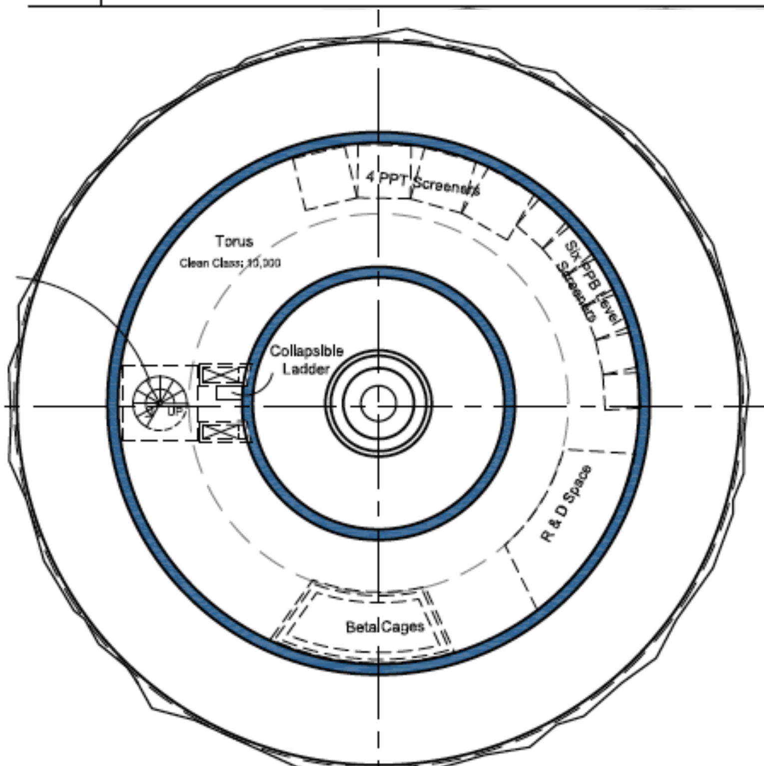
Large Scale QA/QC campaigns will require their own additional project funding.

Managed by a board formed from the members. Grant renewed on a 3-yr cycle

Internal and Independent review processes established. Program Advisory Panel.

Provides a Staged and Community-driven Process. e.g. a generation-3 water-shielded common-use FAARM could be a proposal generated by the Consortium.





Final iteration on a site-independent Screening and Prototyping Facility designed by the DUSEL AARM S4. Inner toroidal lab provides true low bkgd space for sensitive screeners and prototype R&D. Central pool reserved for whole body screening at 10^{-14} g/g U/Th, 10^{-12} g/g K^{40}